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Secure Large-Scale Airport Simulations Using Distributed Computational Resources

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ABSTRACT

To fully conduct research that will support the far-term concepts, technologies and methods required to improve the safety of Air Transportation a simulation environment of the requisite degree of fidelity must first be in place. The Virtual National Airspace Simulation (VNAS) will provide the underlying infrastructure necessary for such a simulation system. Aerospace-specific knowledge management services such as intelligent data-integration middleware will support the management of information associated with this complex and critically important operational environment. This simulation environment, in conjunction with a distributed network of super-computers, and high-speed network connections to aircraft, and to Federal Aviation Administration (FAA), airline and other data-sources will provide the capability to continuously monitor and measure operational performance against expected performance. The VNAS will also provide the tools to use this performance baseline to obtain a perspective of what is happening today and of the potential impact of proposed changes before they are introduced into the system.

INTRODUCTION

The aviation accident rate for commercial aviation in the United States is low, approximately 0.4 accidents per 100,000 departures and has remained stable over the past five years[1]. However, Air Transportation in the United States is predicted to increase by a factor of 3 over the next twenty years and operational problems and accidents in the National Airspace will likely increase with the expected continued growth[1]. The number of accidents will very soon be larger than what the American public will accept. Understandably, in this setting, there is pressure to increase Air Transportation safety by adopting new concepts, technologies, and methods[1].

NASA's Office of Aerospace Technology has established the following goals:

- Reduce the aircraft accident rate by a factor of five within 10 years and by a factor of 10 within 20 years.
- While maintaining safety, double the aviation system throughput, in all weather conditions, within 10 years and triple within 25 years[2].

The joint NASA-FAA safety strategy to achieve these goals emphasizes sharing of safety information and accident prevention[3]. However, the current aviation environment consists of thousands of independent entities: manufacturers, airlines, airports, service providers, research organizations, and government agencies. There does not exist a common architecture for networks, data formats, and application interfaces. Because of the lack of a strategic aviation information infrastructure there are thousands of incompatible data repositories, network systems and applications. The extreme fragmentation of data and application non-interoperability has prevented the U.S. from developing comprehensive, system-wide applications that can monitor, track, and evaluate Air Transportation Safety. Furthermore, attempts to determine the causes of accidents and formulate new strategies to avert them are hampered by the fact that there is a lack of research to support the far-term concepts and technologies[4]. The lack of research is partly a result of the absence of a simulation environment of the required degree of fidelity[4]. The lack of adequate simulation capabilities and the lack of an accurate baseline of the operations of the National Airspace, significantly affect the ability of both FAA management and operational personnel to objectively evaluate new concepts that might improve the safety and efficiency of National Airspace operations. The attendant limited operational knowledge about the current, near-term, and future Airspace-wide operations can results in a lack of effective, strategic, proactive decisions.

FAA personnel who lack this baseline information and a simulation environment at the requisite level of fidelity are affected in at least two ways. First they are affected through their inability to perform system-analysis at the level of the entire National Airspace. Second, they are affected by the lack of a satisfactory environment in which to perform National Airspace-wide testing to assess not only operational impact but also safety implications of new concepts, technologies, and methods. The VNAS will provide an environment for correcting this deficiency.

The vision of a Virtual National Airspace Simulation consists of the following:

- A virtual airspace simulation environment with the highest achievable-level of fidelity required for real-time and fast-time simulation will allow real-time risk assessment.
- The VNAS is used to evaluate new concepts, technologies, and methods for improving the safety of Air Transportation. The VNAS is also used to test new automated tools while they are integrated in the context of the entire National Airspace.
- Because the Virtual National Airspace Simulation provides two-way information flows that incorporate humans-in-the-loop and capture and feedback important aspects of real-time data, pilots in the air as well as people on the ground can interact with simulations.
- Numerous models and simulations maintained by the appropriate domain expertise and run on a distributed network of supercomputers located around the United States collaborate together to generate daily National Airspace baselines.
- Smart tools integrate large quantities of continuously generated monitoring and simulation data from a large number of sources. Real-time Airspace-wide simulation is possible because intelligent query agents can access monitoring and modeling data and multi-fidelity simulation applications via high-speed network connections.
- Through the use of intelligent agents to coordinate communications and other services between numerous data-sources and applications the VNAS dynamically adapts to changing requirements/scenarios.
- The VNAS can be configured to meet the simulation requirements of military, commercial, and general aviation.
- The VNAS can be extended to include multi-modal transportation. For example, both fixed-wing aircraft and rotorcraft can be simulated. Simulation capabilities can also be applied to Space activities.
- Users of the VNAS can dynamically discover, integrate and engage distributed simulation middleware technology via portals.

COURSE OF ACTION OBJECTIVE – CREATE A VIRTUAL NATIONAL AIRSPACE SIMULATION

For the FAA and the air carriers and other service providers to make strategic, proactive decisions about Air Transportation Safety they will need a continuously generated baseline of the Air Transportation System. The highest-achievable fidelity that is needed to create this operational baseline will be a product of the integration of multi-fidelity monitoring and simulation data and tools. Similarly, it will be the ability to integrate insight from different levels of detail that ultimately leads to predictive Airspace-wide safety models. Through a dynamic, adaptable simulation environment that can maintain information about baseline operations and serve as a testbed for strategies to improve aviation safety the FAA, the airlines and others will acquire a perspective of the current state and of the impact of any change before it is introduced.

A dynamic, re-configurable National Airspace-wide simulation environment is chosen as the preferred approach for several reasons. First, The National Airspace of the United States is a large and complex system that is defined by the interaction of a large number of entities. For example, according to airline industry statistics U.S. air-carriers accounted for 7,658,554 departures in 1998[5]. Second, the interaction between many entities produces transient effects that can have an impact on safety but are difficult to capture. A single flight delay of five minutes at one airport that can result in delays for more than 250 other aircraft located at numerous places across the United States illustrates this interdependence[6]. A distributed system of data collection and of modeling and simulation will capture these transient effects. Third, in complex operational environments such as the National Airspace intelligence is decentralized. Information about weather, which plays a significant part in 30 per cent of commercial aircraft accidents, comes from numerous sources[1]. Detection and prediction of risk exposure due to extreme turbulence or weather conditions, such as fog and icing conditions, would allow pilots to make better decisions and possibly break a chain of events that could lead to accidents[1]. Thus, a distributed system-wide simulation environment will dynamically model complex operational systems such as Air Transportation. However, in order to build a flexible and extensible simulation environment that will accommodate numerous models and simulations, scope and objectives statements and a discussion of the technological approach for a VNAS are required.

SCOPE The VNAS will be designed to meet Enterprise-driven, focused requirements of Air Transportation and other Aerospace domains. The focus will primarily be on Aerospace systems, but an effort will be made to ensure that capabilities that are developed also address the needs common to NASA's other Enterprises as well as the needs of the Department of Defense.

OBJECTIVES The proposed approach will focus on three areas: 1) incremental development of models and simulations, 2) Integration and interoperability of data and tools, and 3) gradual enlargement of the infrastructure. Technology that will provide a secure and reliable environment for integrating monitoring and simulation data from numerous sources and extracting knowledge from data will need to be developed.

TECHNICAL APPROACH A revolution in management of information about dynamic, complex operational environments will be required to accomplish dynamic, real-time, interactive National Airspace-wide simulation. Technology, however, has matured to the point where the pacing technical items can be addressed with a high degree of probable success. Intelligent Information Management concepts and related-technology advance this thrust and make it possible to build an Airspace-wide simulation. However, to separate-out and resolve numerous technological issues a high-level roadmap of the VNAS is required.

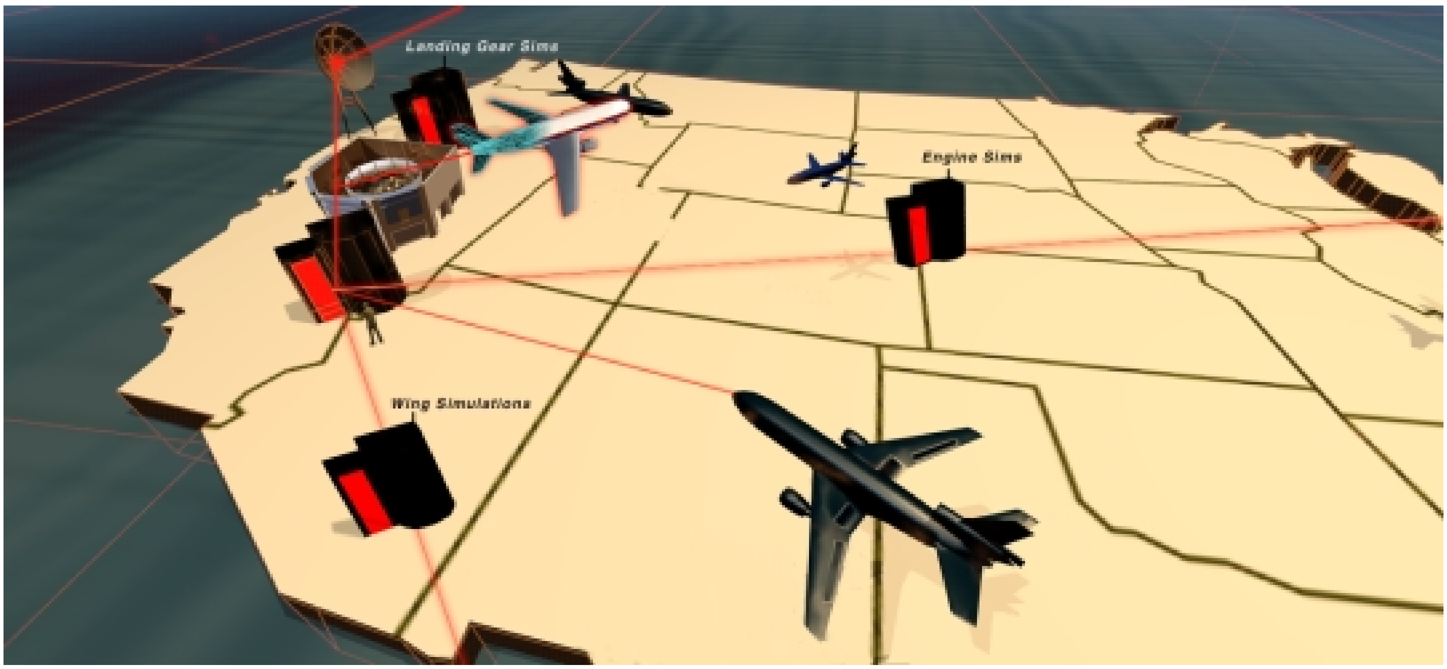

Figure 1. Integration of Monitoring Data and Simulation Data from nodes with various domain expertise in Batch Modeling Process Stage

The development of the VNAS can be logically divided into three major stages:

1. Batch Modeling (non-real time) Process Using Distributed Data and Tools
2. Real-time Simulation with Distributed Data and Tools
3. Interactive, Distributed, High-Fidelity National Airspace Modeling

<u>Stage 1 Batch Modeling Process Using Distributed Data and Tools</u> The objectives are twofold: 1) Develop an understanding of the issues and alternative approaches for a VNAS; and, 2) Design, implement, and test simulation middleware that will support data-integration and interoperability with distributed simulation systems. To maintain a national simulation capability the VNAS must be an extensible and scalable system. An extensible network architecture that can accommodate a growing number of links to data sources and simulation and training facilities will be developed. Similarly, standards for simulation reuse and interoperability such as the Department of Defense's (DOD) High Level Architecture[7] (HLA), and middleware, and related technologies will be tested to determine their flexibility, adaptability and extensibility as they are employed to discover, engage and integrate monitoring and simulation data from a growing number of sources. Monitoring data from distributed, heterogeneous data-collection systems will be integrated with simulation data from numerous aircraft subassembly simulations. An example of the integration of monitoring and simulation from several sources is depicted in Figure 1. Furthermore, a subset of the data collection programs that will provide monitoring data to the VNAS in the Batch Modeling Process Stage is listed in Table 1.

Data Collection Program	Data
Surface & Terminal Operation: SMA[8] & CTAS[9]	Radar-tracks and flight-plans
Enhanced Traffic Management System[10] (ETMS)	Airline Schedules, Flight Plans, and Center Radar Tracks
Performance Data Analysis and Reporting System[11] (PDARS)	Analysis and Reporting based on radar-tracks and flight plans
Aviation Performance and Measurement System[12] (APMS)	Aircraft health and status data from flight recorders
National Aviation Operational Monitoring Service[13] (NAOMS)	Operational safety performance data
Aviation Safety Reporting System[14] (ASRS)	Reports of safety incidents and alerts
National Oceanic and Atmospheric Administration[15] (NOAA)	Weather and surface information

Table 1. Examples of Key Data Collection Programs

Operational data will be supplemented by parameters that are generated by aircraft subassembly simulations. Simulation software will take in monitoring data and generate output in the form of simulation parameters for a particular aircraft sub-assembly. Aircraft simulation data will consist of parameters for engines, wings, and landing gear. Initially, the scope of data collection and simulation will be a single airport, but the scope will gradually expand to cover more of the National Airspace. Similarly, the scope of data collection will expand to include safety data from NAOMS and ASRS, performance data from human-in-the-loop models[16] and simulation data for additional aircraft subassemblies.

The evolving databases of the Batch Modeling Process stage will be based on simulations that are multidisciplinary and on more complete physical models than before the VNAS. Because of this greater fidelity the capabilities of the first stage will enable more sophisticated analysis to be applied to time critical processing. Better analyses will lead to increased understanding of the National Airspace's baseline operation. The baseline of performance that will result from this initial capability will be used to measure expected against operational performance. The improved understanding of baseline performance will lead to better assessment. This in turn will enable researchers to better define concepts. Analyses of concepts can then be fed back into a technological investment portfolio. Furthermore, the simulation capabilities of the Batch Modeling Process will serve as a foundation for the more numerous data sources and network communications of Real-time Simulation and Distributed, High-Fidelity National Modeling in stages 2 and 3.

Figure 2. Expansion of data sources and simulation facilities and addition of two-way information flows in Real Time Simulation Stage

Stage 2 Real-time Simulation with Distributed Data and Tools Information flow in the second stage will need to be two-way rather than one way. Furthermore, the addition of human-in-the-loop models and capabilities to capture and feed back important aspects of real-time data distinguishes the second stage from the first stage. To provide two-way information flow, to allow interaction with human-participants such as pilots and ATC personnel, and to accommodate additional data sources the communications network will expand. An expanded network of connections to high-density airports and other new data sources and to training and flight-simulation facilities at NASA's research and mission centers is shown in Figure 2. Facilities for communicating between the ground and pilots in their aircraft will be established as well as network connections to technical centers, airline operation centers, and command centers. The Real-time Simulation Stage will also experience increased use of grid supercomputer-resources. Real-time grid-performance will be required to address increased accessibility and stability needs as the VNAS expands in scale. In the next stage, which will provide a virtual Airspace-wide simulation environment, collaborative computing will support dynamic simulation capabilities.

Stage 3 Distributed, High Fidelity National Modeling Dynamic interactive, high fidelity, National Airspace-wide simulation distinguishes the third stage from previous stages. Figure 3 shows the VNAS in the final stage when it will be a highly dynamic simulation environment that adjusts for additions and deletions and seamlessly incorporates new operational and simulation facilities. Simulation will be selectable across the range Airport, Region, Country, Hemisphere, and, Planet. Dynamic National Airspace-wide simulations will allow "virtual airspace design." The VNAS will automatically assess and choose the best network and hardware topology to meet demands of the moment. Rapid turnaround and re-assembly capabilities will enable trade studies and "what-if" scenario evaluation as well as high-fidelity National Airspace-wide analyses. Furthermore, to achieve a goal of gradual improvement in the quality of models and simulations the VNAS's development will involve extensive collaboration with researchers who are developing models and simulations, that are related to the National Airspace.

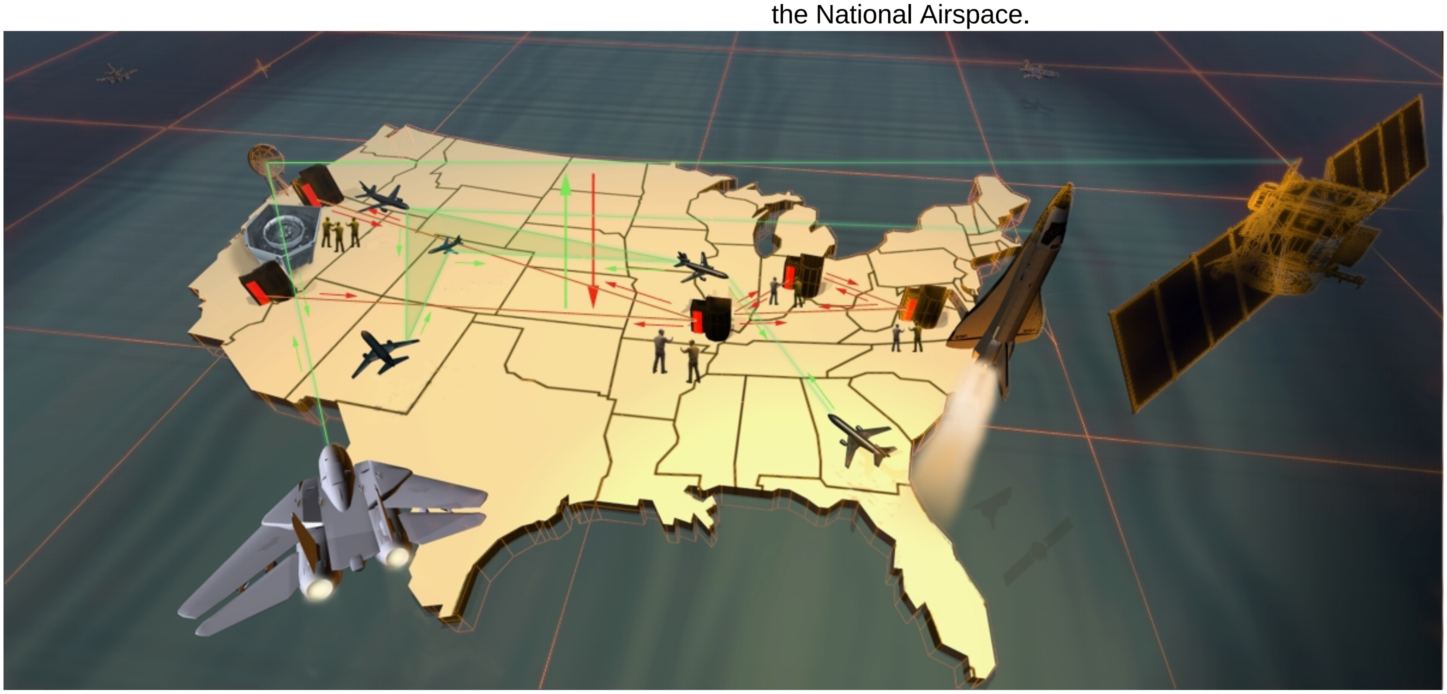

Figure 3. Dynamic, re-configurable Airspace-wide Simulation Environment in the Distributed High Fidelity National Modeling Stage

ROLE OF DEVELOPERS OF MODELS AND SIMULATIONS WITH DOMAIN EXPERTISE AND FEEDBACK FROM DIGITAL FLIGHT DATA Researchers and domain experts who are independently developing models such as human performance or, aircraft subassembly simulations will plug in the models and simulations that will be integral parts of the VNAS. These experts in areas such as Human Factors and Jet Propulsion will develop the models and simulations that will be incorporated into a system-wide model. Personnel located at the centers of domain expertise such as propulsion (NASA Glen Research Center) and landing gear (NASA Langley Research Center) will use digital flight-data to evaluation data produced by simulations of aircraft subassemblies. Corrections or improvements that result from analyses will be fed back into the appropriate model or simulation. This feedback process will produce incremental improvements in the quality of Airspace-related models and simulations. Integration tools will need to accommodate the addition of distributed, multi-fidelity simulation tools and new concepts and tools called Intelligent Information Management will support the integration of numerous applications and data of different fidelities.

UNDERLYING INTELLIGENT INFORMATION MANAGEMENT CONCEPTS AND TOOLS Intelligent Information Management involves locating, organizing, and adding value and access to data throughout its life in an enterprise. To extend the fidelity of safety simulation to the highest achievable degree and provide seamless, user-transparent access to Air Transportation safety information a revolutionary technology leap in Intelligent Information Management is established. The Intelligent Information Management concepts that are provided below encompass a national strategy for discovering, engaging, storing and organizing aviation/aerospace monitoring and simulation data and applications. An expandable communications network and an extensible architecture allow Intelligent Information Management's suite of services to be dynamic, flexible and adaptable.

<u>The Advanced Communication Network</u> The scope of the Advanced Communication Network is represented in Figure 3. It will be accessible via secure portals and will provide the performance needed for access to simulation data and tools distributed across the United States.

<u>Intelligent Information Management Architecture</u> Because the secure, adaptable bus-like architecture accommodates a wide range of network-communication and processing needs it is the key enabling technology that will allow full use of Air Transportation safety information. Intelligent Information Management's suite of smart services collaboration with each other and communicate with users via this network. Also, because this architecture is adaptable to common needs of DOD and NASA's other Enterprises in can help manage complex operational environments in Space. The progress of other NASA groups that are working to create more productive distributed scientific environments such as the IsoWAN, a science and engineering information and services framework, will be monitored[17]. A complete picture of the Intelligent Information Management Architecture, however, requires some examples of smart services that collaborate with each other and communicate with users via this architecture.

<u>Intelligent Information Management</u> Intelligent Information Management's services will create a re-configurable, interdisciplinary simulation environment by integrating high-performance computing, data storage and organization, and simulation and analysis capabilities. These services will enable the VNAS to be a "service unifier" that can weave services together, creating a grid or cloud of electronic offerings that feed into each other. A grid-structure will allow users of simulation services to mix and match numerous simulation services such as XML-conversion tools for data integration or knowledge extraction. Descriptions of examples of Intelligent Information Management Services are provided below.

- <u>Security</u> Extraordinary security measures are taken to prevent unauthorized access to data and information. Data, models and simulations may be proprietary or sensitive, and, therefore, require special controls to ensure that only authorized people can access them.
- <u>Intelligent Data Integration</u> Smart Integration tools that discover inaccuracies, limitations, or contradictions of processed data and raw inputs such as Idaho National Engineering and Environmental Laboratory's Merlin Mediation System[18] and software agents will be used to manage the burgeoning amounts of data as more and better sensors are added and the volume of monitoring and simulation data about the National Airspace grows.
- <u>Dynamic, Flexible Access-Services</u> Access of this kind will be accomplished through agent collaboration that uses standard protocols for specifying and locating simulation services. Intelligent-access to heterogeneous data, and query, analysis and other services will also require software agents. Query processing will be improved by using meta-data and ontology, and, software agents will help simplify the complexities of distributed computing. Agents will interact with users, identify information sources, plan queries, and navigate between different ontology on aviation safety information.
- <u>Standards</u> Seamless access to numerous Aerospace-specific service portals will require standard protocols for specifying, discovering and engaging Intelligent Information Management Services. Standards for specifying VNAS services and for indexing and lookup of services will allow users of this Airspace-wide simulation environment to dynamically locate VNAS services via portals. The eXtensible Markup Language (XML) is a standard of World Wide Web Consortium (W3C) that specifies a format for structured documents and data on the Web[19]. Because of XML's universality and support of semi-structured data, monitoring and simulation data can be converted to XML and stored in specialized databases for query, analysis and visualization. Recent Web-based standards such as Web Services Description Language[20] (WSDL), and, Universal Description, Discovery, and Integration[21] (UDDI) and DOD's HAL will warrant monitoring.
- <u>Two-way Communication Capabilities</u> Tools that support two-way information flows between interdependent systems will be developed. They will capture and feed back important aspects of real-time data flows such as relaying real-time risks

assessments via ground-to-air communication links to pilots and FAA personnel.

- Smart Simulation Tools Intelligent simulation tools are anticipatory and exploit opportunities or mitigate risks. Development of the infrastructure for VNAS will include smart tools that not only indicate past and current states of the ATC systems but also predict likely future states.
- Human Centered Computing (HCC) Concepts The focus of these concepts is on developing computer systems that are well suited to human abilities[22]. Artificial intelligence programming methods and other HCC concepts may form the basis for a new generation of sophisticated computational aids for pilots, the FAA, and researchers who are studying the National Airspace.
- Supercomputer Computational Services A high performance grid made up of a distributed network of supercomputers will provide large-scale computational resources to support the integration of hundreds of aircraft performance models with real-time radar tracks and status data for National Airspace-wide simulation. Grid computational resources also will be required to "data-fuse" thousands of airport schedule, status and configuration data sources with real-time, Airspace-wide simulations for concept baselining and definition.

Building the VNAS will be a gradual process. VNAS prototypes will be developed incrementally and analyses of the prototypes will be used for technology evaluation and concept definition.

VIRTUAL NATIONAL AIRSPACE SIMULATION PROTOTYPE

Technical Approach Initially the focus will be on integration of data sources and on the development of middleware components that can be used to incorporate legacy models and simulation software into a multi-fidelity environment. Later, the network will be expanded to include simulation facilities at NASA's research and mission centers such as NASA Ames' Crew Vehicle Systems Research Facility[23]. In addition, VNAS prototypes that incrementally add new technology will be built at various points.

Building an initial prototype environment that includes integrating with a supercomputing grid provides opportunities to identify the underlying technological issues such as extensibility and scalability to a national level. Early on, security and network communications also will be addressed because data, models and simulations will possibly require compartmentalized views and data and applications will be distributed across the United States. Also, integration of monitoring and simulation data and applications will be addressed because object-models of components of the National Airspace will be numerous and complex and will be made up of multi-fidelity data. Grid-performance and data-management are critical areas and will need to be exercised to evaluate grid-services. Creating a prototyping environment also provides experience in developing an understanding of the relationships between Intelligent Information Management Concepts and Tools and a number of aircraft subassembly simulations.

Intelligent Information Management and Aircraft Subassembly Simulations

Today an initial prototype of the National Airspace Simulation runs on NASA Ames' Information Power Grid[24] (IPG) testbed computers. The VNAS prototype serves as a demonstration capability of Intelligent Information Management and runs on IPG computers at Ames and Glen Research Centers. Grid security and job management services allow subassembly simulations and data dissemination and retrieval to be controlled from a central Intelligent Information Sharing node. Requests for engine and wing simulations for flights at Atlanta's Hartsfield International Airport are made via a Web-browser. A browser can also be used to view graphs of simulation parameters when simulations have finished. The Intelligent Information Sharing node manages interactive requests by controlling engine, landing gear and wing simulations on the remote machines. IPG's security software manages logon, user authentication and authorization and job-submittal software provides the mechanism for submitting simulation requests to the testbed computers. A secure file-transfer service is used to exchange data between the three computers. Intelligent Information Management services are used to integrate monitoring and simulation data and to control routine, automated, batch processing of an entire day's flights.

The four major parts of the initial simulation prototype and the centers of expertise that are responsible for aircraft subassembly simulations are listed in the table 2.

Expertise/VNAS Component	**Center of Expertise**
Information Technology: Intelligent Information Management[25]	NASA Ames Research Center
Aeropropulsion: Numerical Propulsion Simulation System[26] (NPSS)	NASA Glen Research Center
Airframe Systems: Boeing 737 & 757 Simulators[27,28]	NASA Langley Research Center
Wing: Wing Simulation[29]	NASA Ames Research Center

Table 2. Domain expertise for aircraft subassembly simulations

From a simulation-integration point of view every simulation is similar. Each simulation site receives input data from the Intelligent Information Sharing node. The input data is processed by simulation software that, in turn, produces simulation data that reflects the output of a particular aircraft subassembly.

The focus of the initial prototype is on basic simulation and examples of simulation data from each of the three simulations in the initial prototype appear in table 3.

Engine Simulation Parameters	Landing gear Simulation Parameters	Wing Simulation Parameters
Compressor and Turbine inlet/outlet temperatures and pressures	Landing-gear forces	Drag and Lift coefficients

Table 3. Representative Parameters from 3 Subassembly Simulations

The simulation parameters generated by subassembly simulations are integrated and stored for analysis, visualization, and data mining by the Intelligent Information Sharing node. For example, weather data, flight-plans and radar-tracks and simulation parameters are linked together into a consolidated-view. Monitoring and simulation data that has been integrated through the use of XML conversion tools can be viewed via a visualization tool or mined and analyzed for risk exposure. The list of parameters from engine, landing gear, and wing simulations will, however, continue to grow.

Near-Term Plans to Extend and Enhance VNAS Prototype

Future prototyping activity will continue to exploit middleware and network technologies that support the simulation capabilities and needs of the Batch Model Processing, Real-time Simulation, and Distributed High-Fidelity National Modeling stages of the VNAS. A major objective for the near-term will be developing an architecture for data integration and interoperability between simulation systems that is both extensible and scaleable to a national-level.

Future research and development will take place in six areas. First, aircraft subassembly simulations will continue to be refined and extended. Second, additional data sources will be added and the scope of monitoring data will be gradually expanded for greater coverage of the United States. Third, the VNAS prototype will incorporate smart middleware and technologies such as XML-converters and advanced full-text search engines to integrate data from heterogeneous databases and extract knowledge from them. Fourth, technologies that will enable two-way information flows such as capturing and feeding back safety information from multi-discipline flight simulations to pilots via ground-to-air/air-to-ground links will be tested. Fifth, developers of the VNAS prototype will continue to investigate proposed standards and technology that supports Aerospace-specific Intelligent Information Management. Sixth, collaboration with groups who are working to create large-scale computational grids will continue. Descriptions of a subset of future activities in these six areas are provided below.

Models and Simulations Developers of the wing simulation will focus on two objectives. First expand the diversity of aircraft that can be simulated at a simple level. Second, refine algorithms to enhance aerodynamic fidelity of wing simulations. Developers of engine simulation software will extend simulations to detect risk exposure and to predict engine-life. Later, in parallel, both engine and wing simulations will be enhanced to include the physical effects of icing and noise. Landing gear simulations for the B757 will be incorporated when it becomes available Collaborations will begin between the developers of Intelligent Information Management and modelers of human-performance to inject human-performance into simulations.

Monitoring Data From Key Collection Programs In the near-term, additional monitoring data such as radar-tracks and flight-plans from ETMS and PDARS and aviation safety reports from NOAMS and ASRS will be gradually added to evolving aviation safety databases. Additional data sources will improve data fidelity and the scope of monitoring data will also be expanded from a single airport to greater coverage of the United States.

Intelligent Data Integration Merlin acts as a middle layer between applications or services and data warehouses and is an example of smart middleware that "resolves data access and integration issues."[16]. To understand Merlin's capabilities such as detection of inaccuracies, limitations, or contradictions of processed data and raw inputs, Merlin will be used as one of the components of simple data access and query services. Additional data sources will be gradually added and, with each increment, performance and Merlin's ability to scale will be evaluated.

Two-way Information Flows Early in the next prototyping phase developers of the VNAS will test ground-to-air communication technologies that can be integrated with the prototype VNAS. A ground-to-air communications facility will enable an Intelligent Information Sharing node to relay safety-related simulation information to a pilot in an aircraft and allow the pilot to interact with the simulation.

Standards To achieve the goal of seamless access to Aerospace-specific Intelligent Information Management services a standard protocol for simulation and other engineering services must exist. XML is a format for semi-structured data on the Web and is a standard of the World Wide Web Consortium (W3C). XML's universality and structure will allow the VNAS prototype to put together distributed data and applications from numerous sources and extract knowledge from them. To test XML's suitability as a standard way to exchange information about Airspace-wide simulations monitoring and simulation data will be converted to XML. XML-converted data will also be inserted into specialized databases to test advanced, full-text search capabilities. The progress of other Web-based standards such as WSDL and UDDI that may support dynamic Intelligent Information Management will be followed.

Supercomputer Computational Services The progressively greater computational capabilities that will be required for National Airspace-wide simulation are suggested by the current and future requirements listed in table 4.

Current Capability	**Capability Needed By 2010**	**Capability Needed by 2020**
Aircraft trajectories + optimum spacing for one airport -> 100 million floating-point instructions (MF), 100 mega-bytes per simulation	Aircraft trajectories + optimum spacing for entire nation -> 10 billion floating point instructions (GF), 20 giga-bytes per simulation	Aircraft trajectories + optimum spacing + surface movement advisories for entire nation -> 20 GF, 1 terra- bytes per simulation
Navier-Stokes, airframe only, cruise --> 10 hrs	Multi-discipline simulation, airframe only, landing/takeoff --> 1 hr	Multi-discipline simulation, airframe + propulsion, landing/takeoff --> 1 min

Table 4 VNAS' Current and Future Need for Computational Resources

As additional monitoring and simulation data become available the need for computer resources and network bandwidth will also increase[30]. Additional models such as Human Performance will become available and will be added to the VNAS Prototype. Similarly, subassembly simulations will expand and the list of parameters from engine, landing gear, and wing simulations will continue to grow. Thus, to meet the future requirements of a dynamic, extensible, adaptable National Airspace-wide simulation capability the activities of programs that are working to improve the computational infrastructure for scientific discovery must be leveraged. The following are examples of groups who are working to extend grid resources:

- NASA Ames' Information Power Grid
- National Science Foundation's National Partnership for Advanced Computational Infrastructure[31] (NPACI)
- University of California San Diego's San Diego Supercomputer Center[32] (SDSC)
- University of Illinois' National Center for Supercomputing Applications[33] (NCSA)

The work of these groups is likely to continue to progress. This continued growth in capability will result in faster hardware speeds, more use of distributed and parallel computing, and increased human/computer interface efficiency. Improvements in Supercomputer-grids will in turn lead to reduced turn-around times for National Airspace-wide simulations. Developers of VNAS prototypes will continue to work with these groups to understand the capabilities of grid-services such as security, job-control, and data management as they evolve.

CONCLUSION

For the FAA to increase the throughput of Air Transportation while maintaining, or even reducing, currently low accident rates, requires a National Airspace-wide simulation environment that has the highest achievable degree of fidelity. The solution described in this paper, Intelligent Information Management, will provide the underlying infrastructure necessary to support a Virtual National Airspace Simulation. The VNAS will be an enabling architecture that is both extensible and scalable to a national-level. The VNAS will link together legacy and future models and simulations as they are developed. The VNAS infrastructure will consist of a distributed network of supercomputers that are connected together through secure, high-speed ground and satellite links. The VNAS will provide two-way information flows that will enable pilots and FAA personnel to interact with simulations. Smart simulation and intelligent information-integration tools will support the management of information and will provide the capability to continuously monitor and measure operational performance against expected performance. From this National Airspace-wide simulation environment the FAA, the airlines, and other service providers of Air Transportation will have a continuously generated performance baseline of the National Airspace. They will then be able to extract insightful interpretations of the health and safety of the National Airspace from operational baselines. These insights, in turn, can be the basis of new concepts for improving aviation safety. New concepts can then be inserted into real-time National Airspace-wide simulations and analyses of performance can be a basis for evaluating proposed methods and technologies and making proactive decisions about improvements to aviation safety.

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